Neutrino DIS at MINERvA

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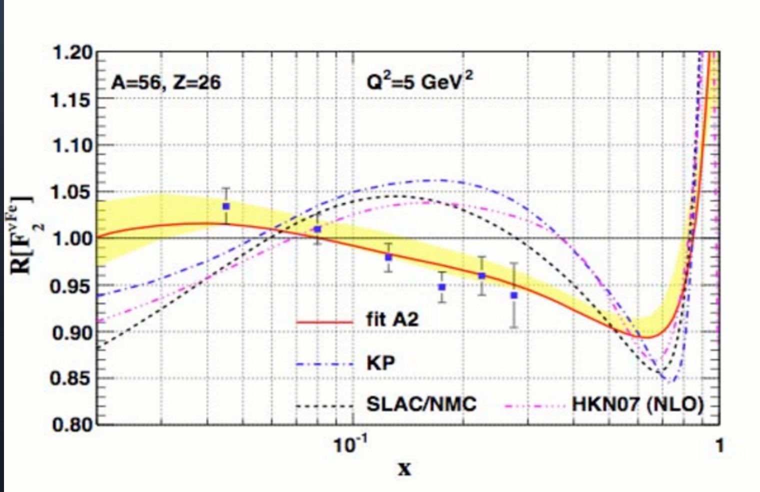
Neutrino DIS: Why Study it?

•Neutrino DIS is sensitive to different Physics than charged lepton scattering:

- Probe specific quark flavors through ν and $\bar{\nu}$ scattering.
- Explore strange quark contribution.
- Resolve xF_3 access valence quark distribution.

Unanswered questions in nuclear physics:

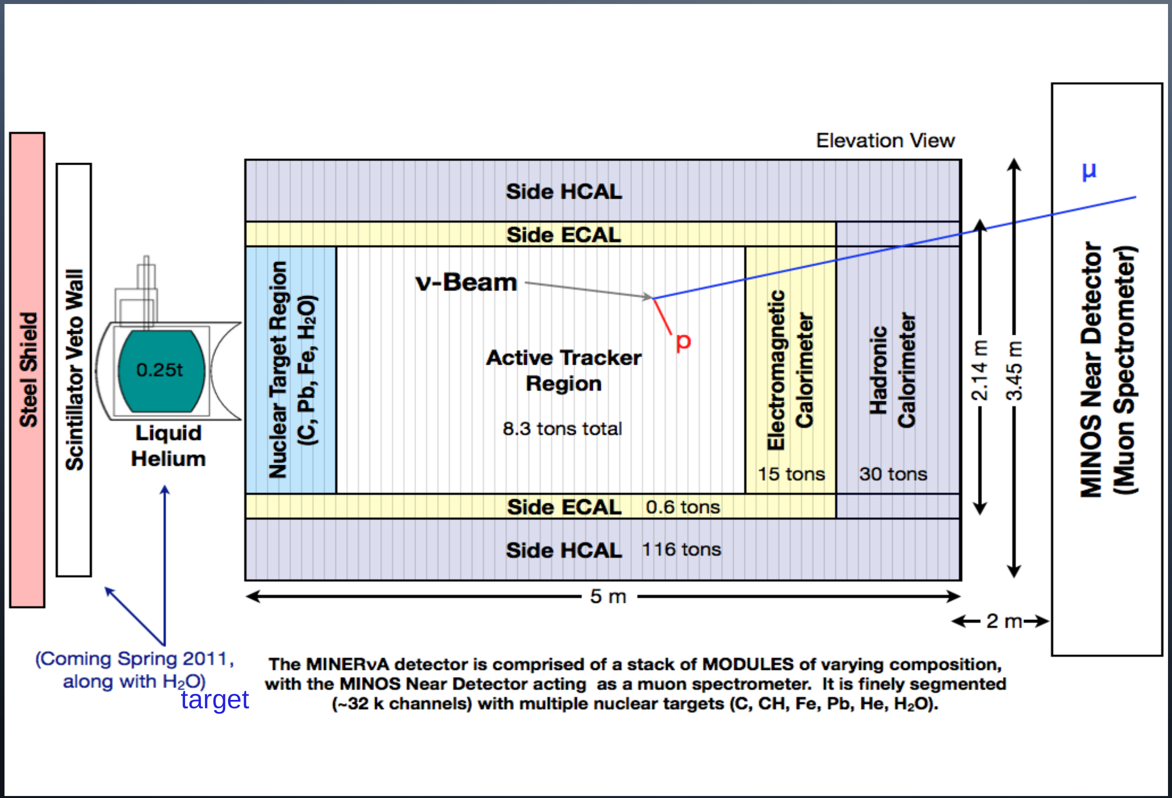
Are nuclear effects different for the weak interaction than the Electromagnetic?
What is their sign/ magnitude?
Do they exist at all?

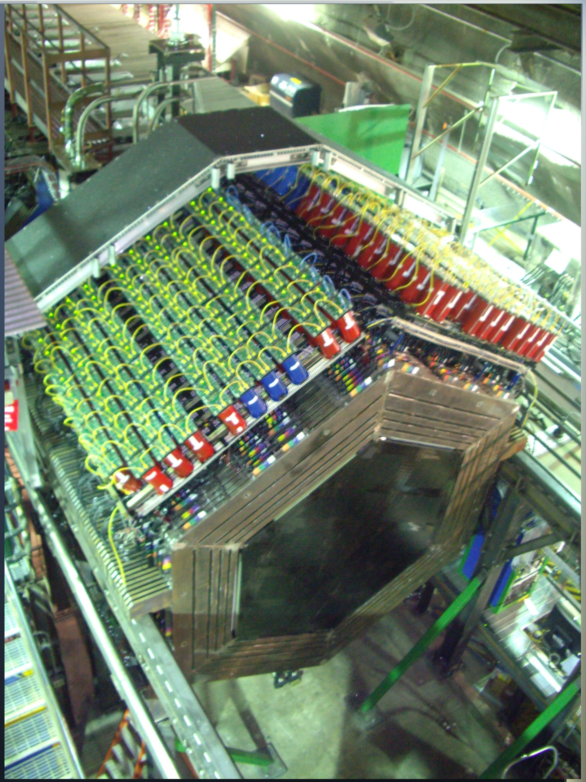


CTEQ analysis of nu-Fe scattering
ArXiv: 1012.0286 [hep-ph]

More data is needed to address this physics!

Enter MINERvA:

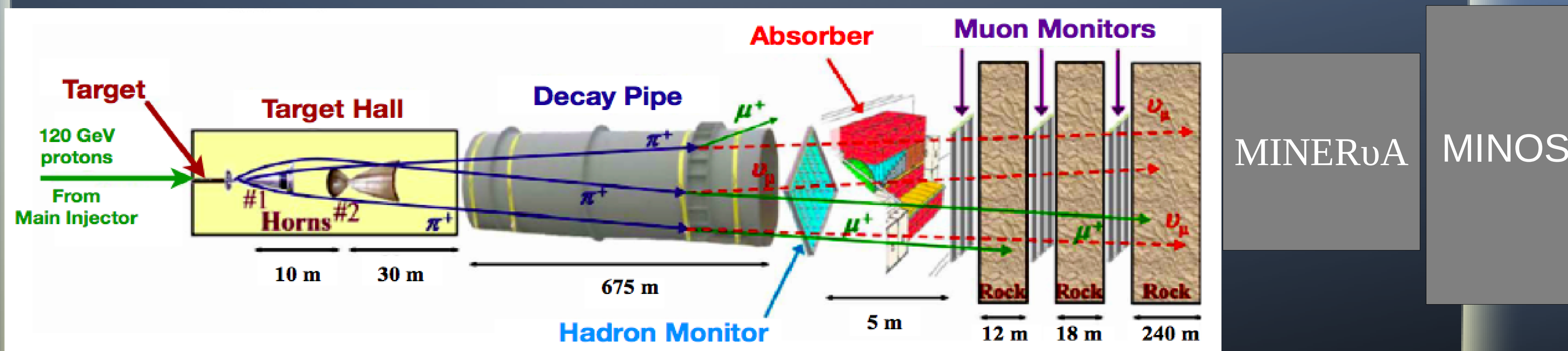


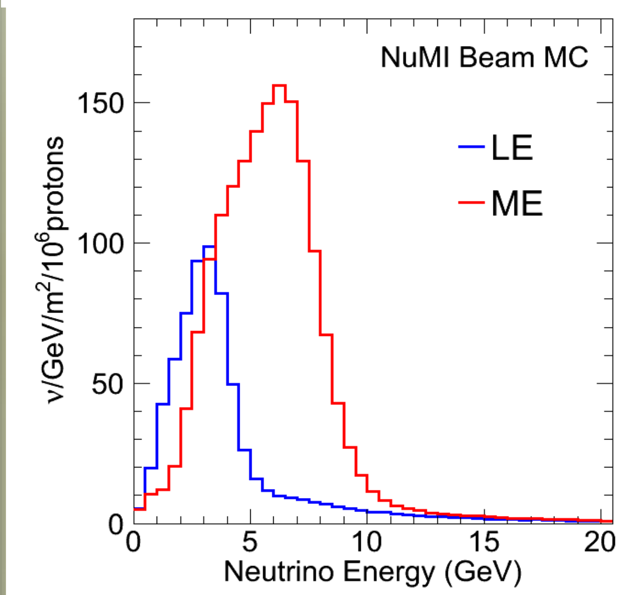


MINERvA under construction with modules visible

- Planes of scintillator strips, surrounded by steel outer frames make up hexagonal modules.
- 120 modules in the final detector.
- Nuclear targets of Fe, Pb, He and C in the same neutrino beam allow MINERvA to make many A-dependent physics measurements.
- MINOS detector used for escaping muon ID and reconstruction.

The NuMI Beamline:





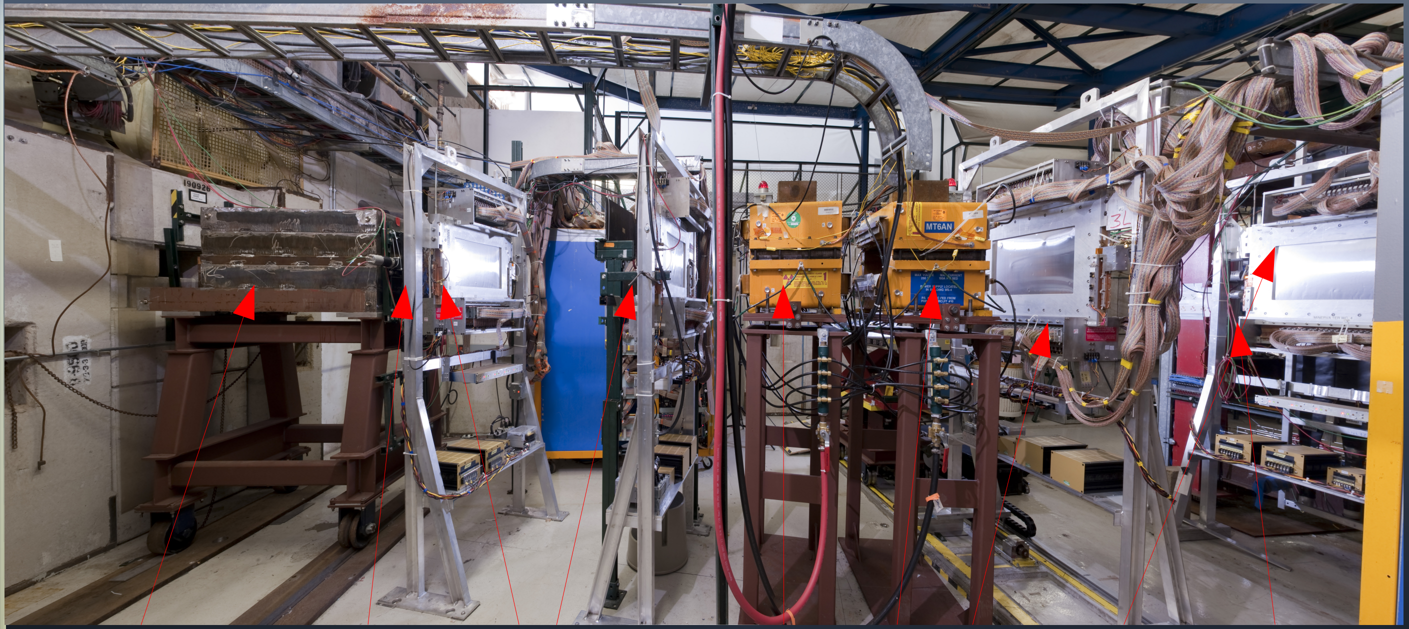
MINERvA sits in the NuMI beamline at Fermilab in Batavia, IL.

Movable target and horns allows for different neutrino energy spectra.

Muon monitors count muon flux at various lengths of rock, allows us to monitor neutrino beam *in situ.*

This talk focuses on LE beam run, order of magnitude more DIS events expected in ME beam run.

MINERvA Test Beam Experiment



Goal: To assist reconstruction and simulation of hadrons using beams of known particles and momenta (p, μ, π).

Collimator	TOF	WCs	Magnets	WCs	TOF

40 planes of Scintillator.

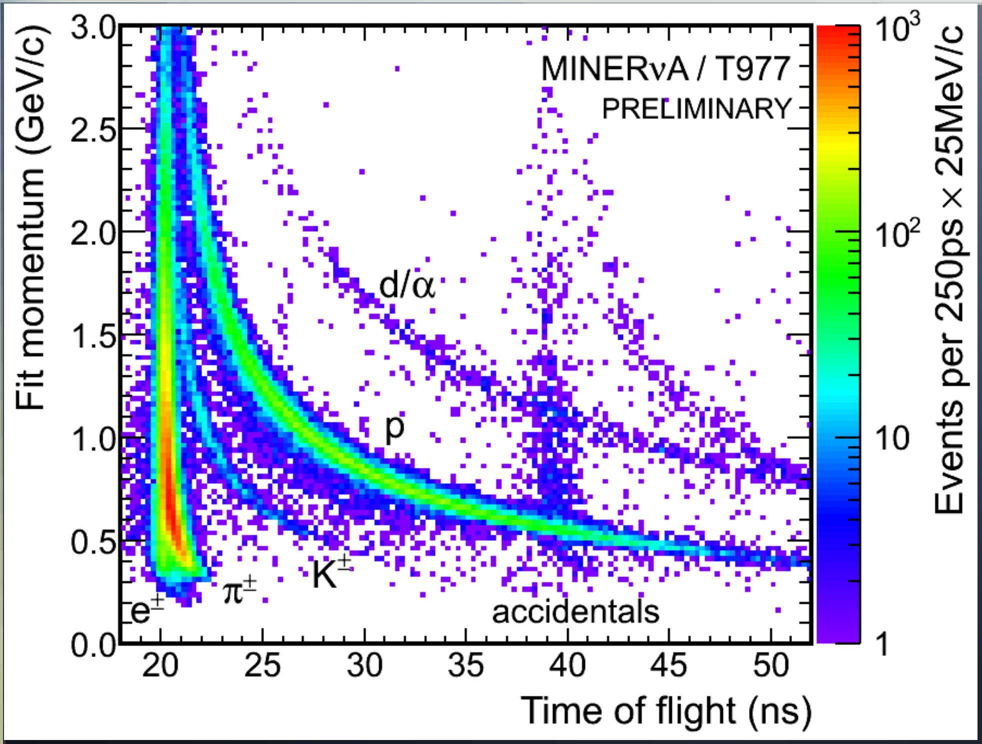
20 planes Fe, and 20 planes Pb to mimic Calorimeters.

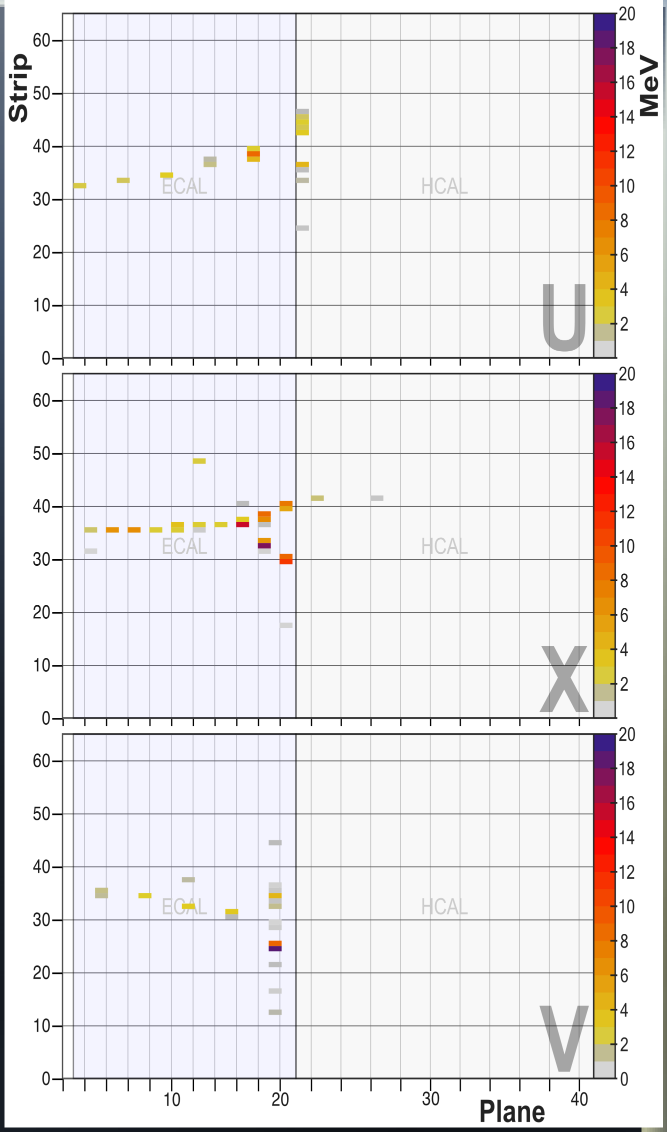
Can configure to mimic any part of the main detector.

Beamline MINERvA designed.

Took data Summer of 2010 at FTBF.

Test Beam (cont'd)

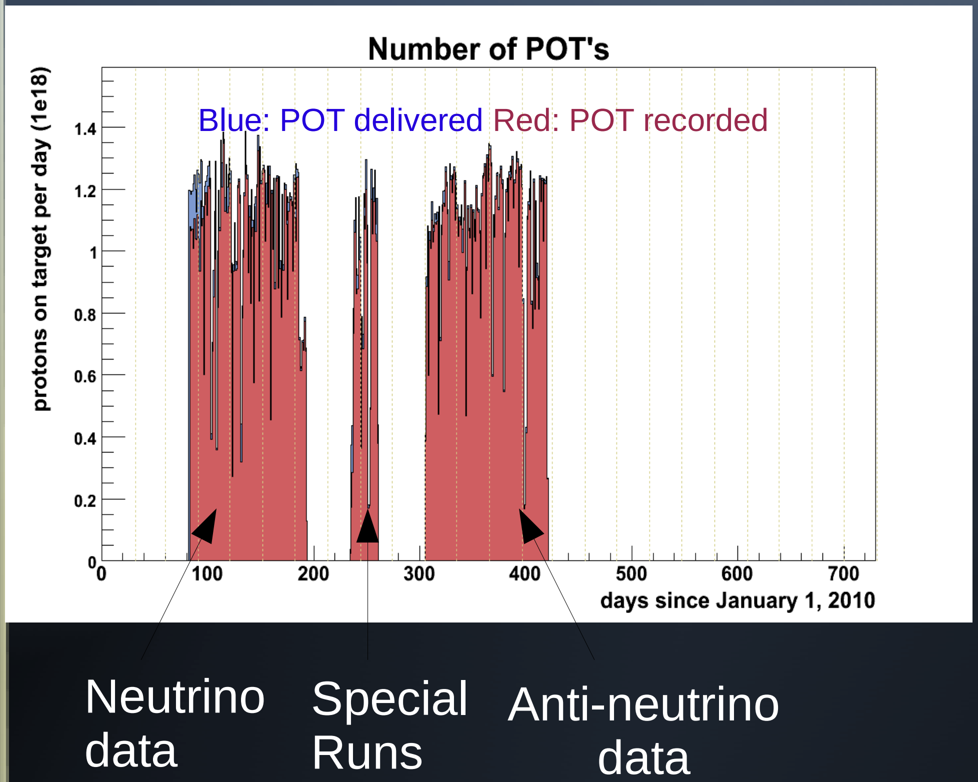




Time of flight used for particle identification.
Magnets and wire chambers provide momentum information.
Detector response to hadrons vital for neutrino DIS.

709 MeV/c Pion in MTest

MINERvA Run Plan

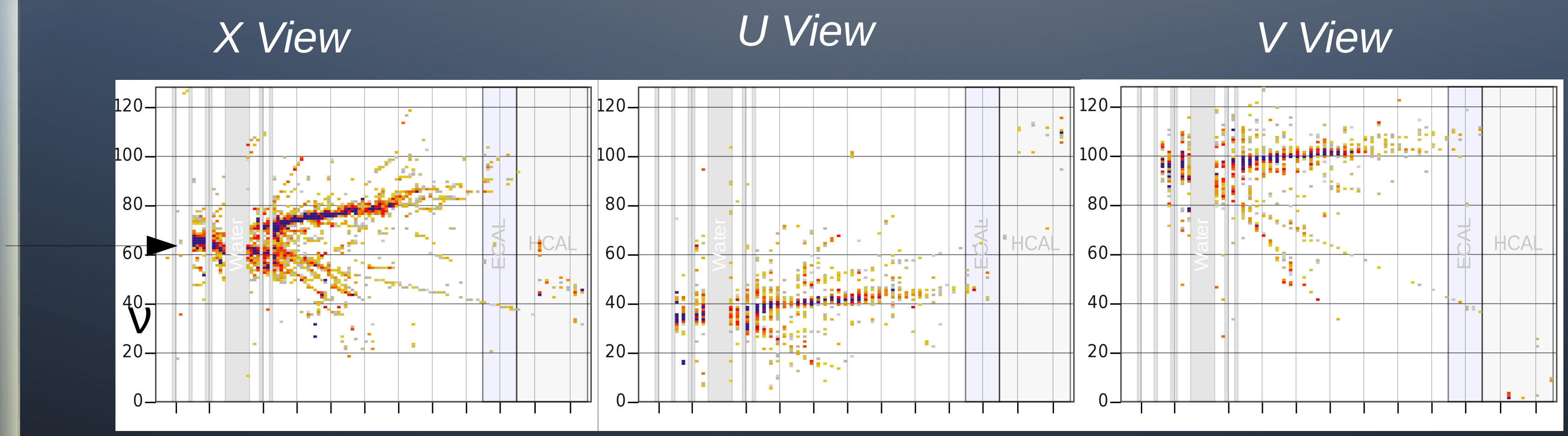


MINERvA has been approved for a physics run of 4×10^{20} protons on target (POT) of LE neutrino beam, plus 0.9×10^{20} POT of special runs of varying horn current and target position to determine neutrino flux of LE beam.

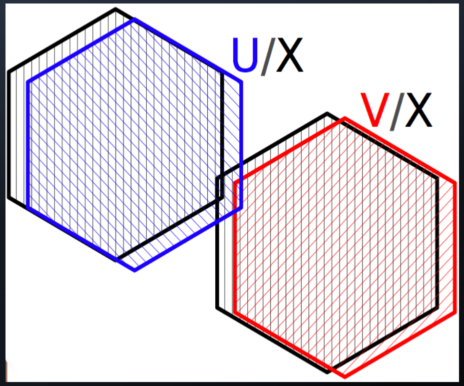
2013: Begin accumulating 12×10^{20} POT of ME (~ 6 GeV mean energy) neutrino data. An order of magnitude more DIS events.

1.2×10^{20} POT each of neutrino and anti-neutrino data currently on tape.

Neutrino DIS In MINERvA



X U and V views are three different plane orientations to give a stereo view.



X-axis: Module number Y-axis: Strip number.

Resolvable muon track, as well as a characteristic hadron shower.

Define neutrino DIS by four momentum transfer squared (Q^2) be greater than 1 GeV^2,
invariant hadronic mass (W) be greater than 2 GeV.

$$Q^2 = 4E_\mu E_\nu sin^2\left(\frac{\theta_\mu}{2}\right)$$

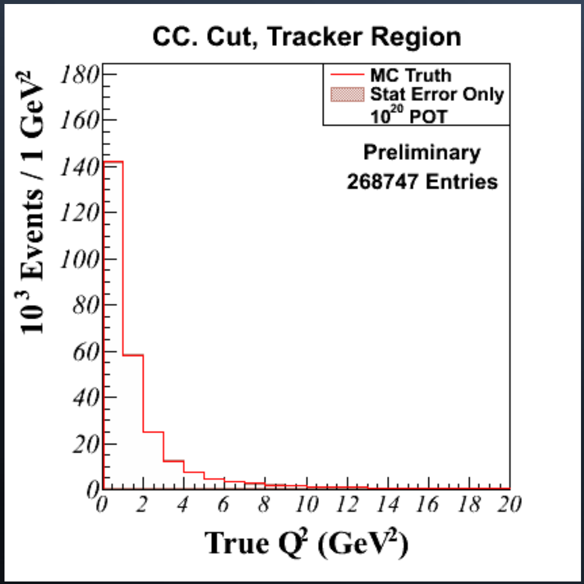
$$W^2 = M_N^2 + 2M_N E_H - Q^2$$

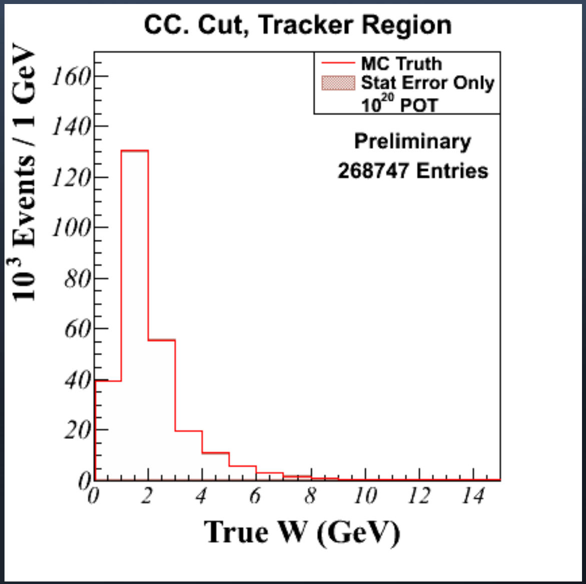
Details of Charged Current (CC) Events

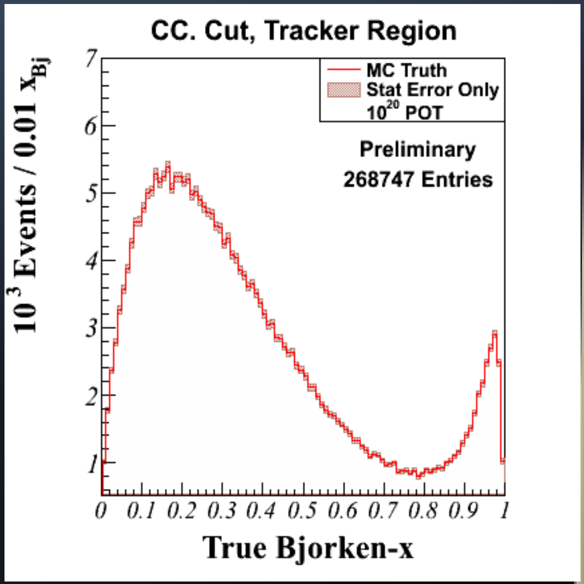
The NuMI neutrino beam tuned to neutrinos is 95% ν_μ 4% $\bar{\nu}_\mu$

ν_μ interact with atomic nuclei to produce μ^- as well as final state hadrons.

Most easily recognizable signature is a long μ^- track.





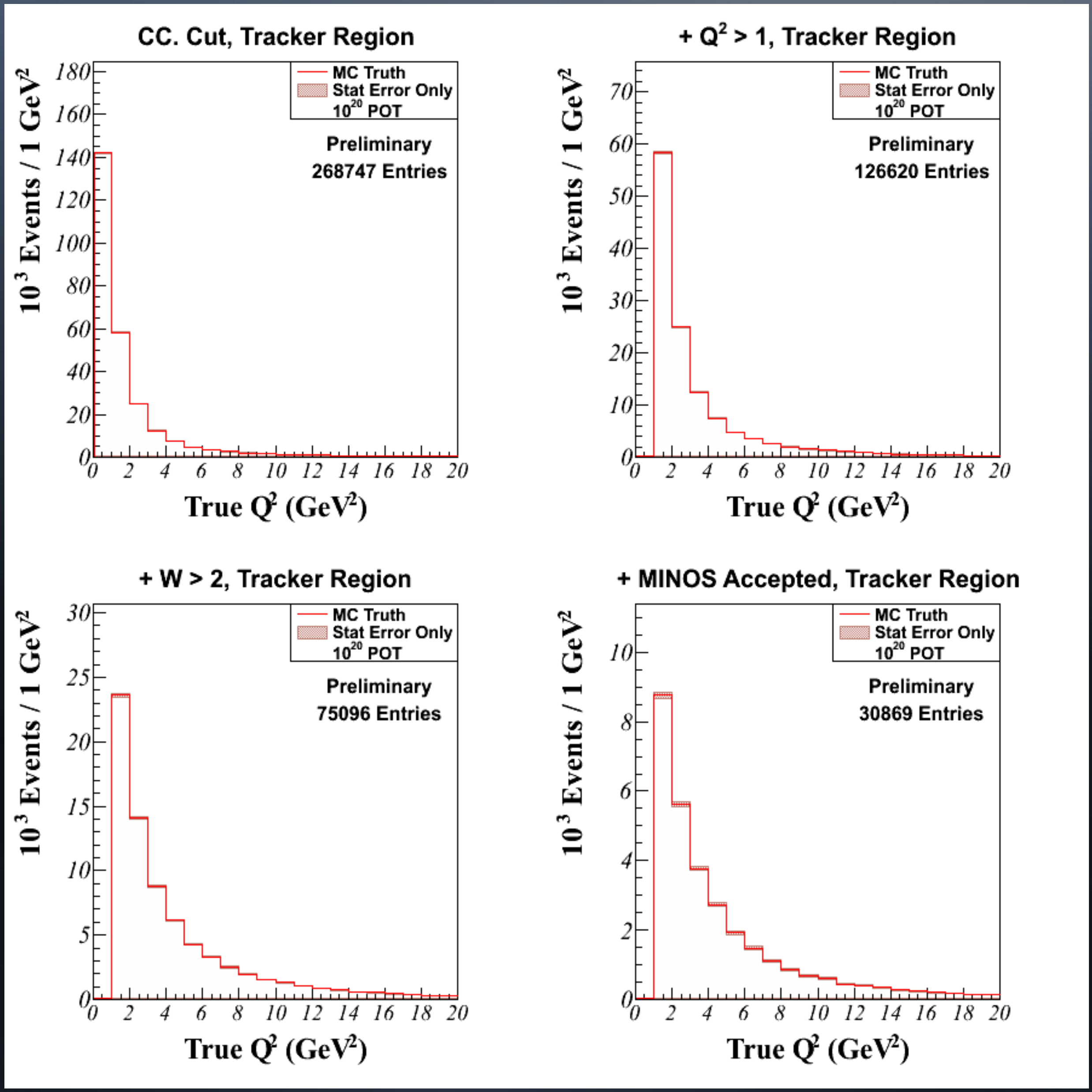


Q^2: Four momentum transfer squared W: Invariant hadronic mass x_{Bj}: Bjorken-x

Three most important kinematic variables for studying DIS.

Neutrino CC DIS defined by $Q^2 > 1$ and $W > 2$, and a μ^- in the final state.

CC DIS Q^2



Q^2 of neutrino events generated in MINERvA.

Events generated in Tracker region of the detector.

Q^2 and W cuts are harsh on LE beam.

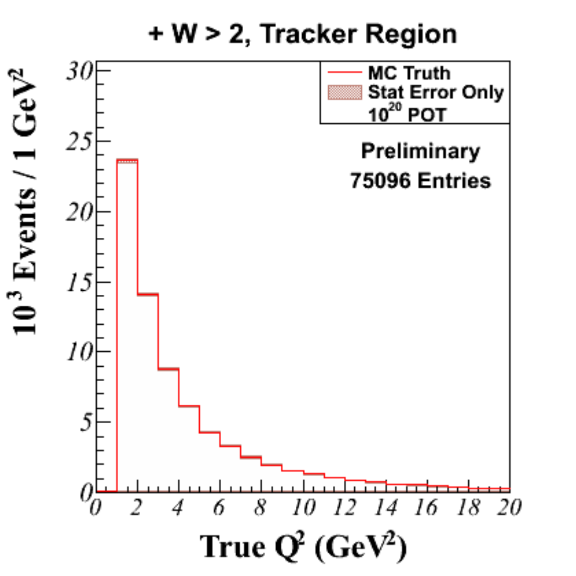
“MINOS Accepted”: muon was tracked into MINOS detector.

MINOS as a Muon Spectrometer

MINERvA cannot stop high energy muons or determine muon charge.

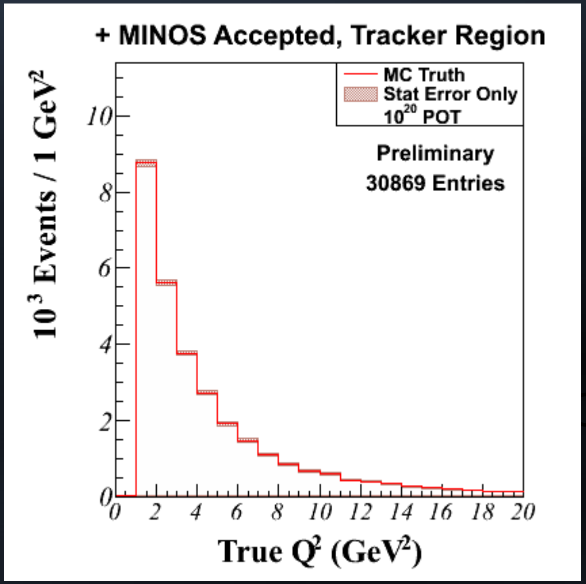
For muons which exit out the rear of the detector we attempt to match our muon tracks to MINOS muon tracks.

Not all events will make it to MINOS. We use the MIENRvA MC to simulate our acceptance, and see how it affects measurements



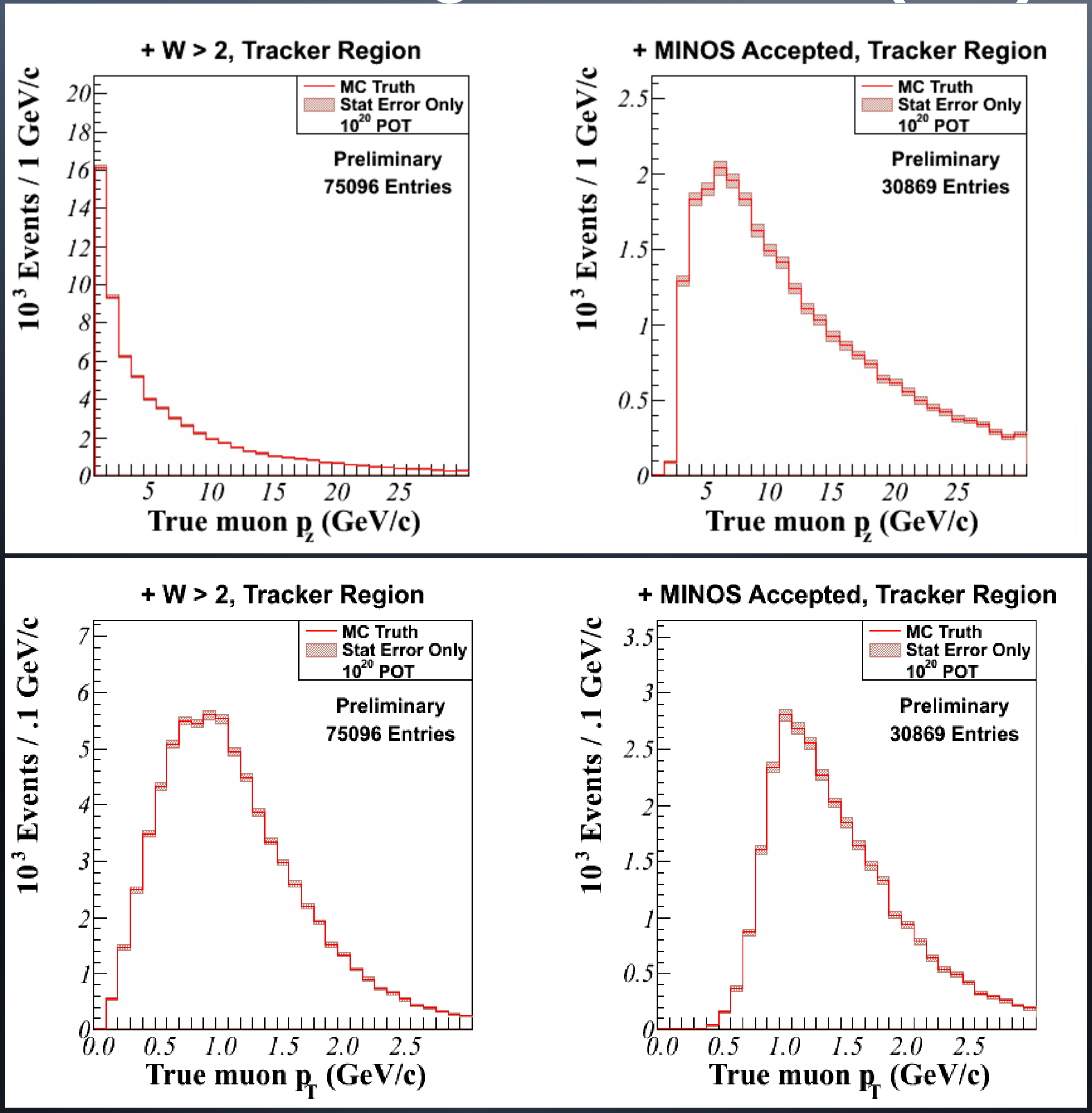
With CC, DIS cuts applied

Simulate acceptance



With CC, DIS cuts applied

Kinematics of Final State Muons: Charged Current (CC) events



Momenta along (z) / transverse (T) beam direction of final state muons from neutrino events generated in MINERvA.

Events generated in Tracker region of the detector.

Mean Low Energy Beam energy ~3 GeV.

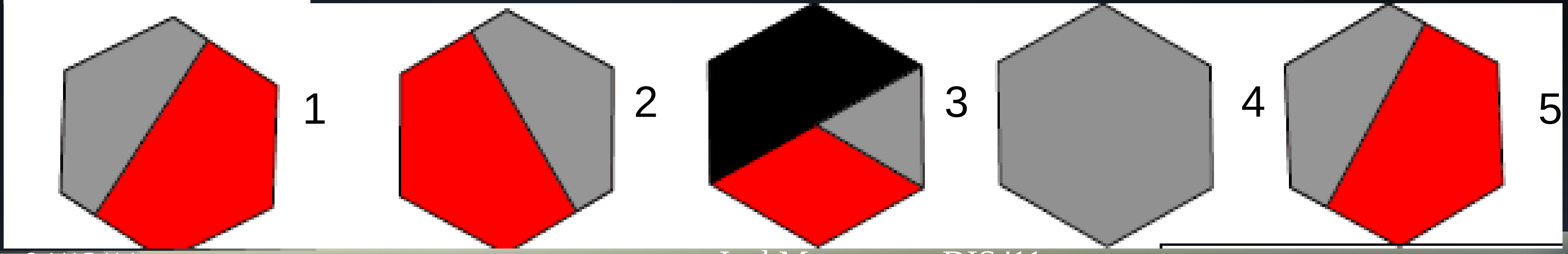
Nuclear Targets in MINERvA

MINERvA employs nuclear targets of Fe, Pb, He and C.
One of the goals of MINERvA is to study nuclear effects as a function of A.
A FIRST systematic study of nuclear effects with neutrinos.
Targets in the same beam leads to systematics canceling

*1×10^{20} POT, **1/4 of our LE approved data run***

Material	CC Events	CC DIS	MINOS Accepted
Tracker (CH_2) (5.0T)	296K	75.1K	30.1K
Fe (0.98T)	52.9K	14.8K	4550
Pb (1.01T)	57.4K	16.1K	4921
Graphite (0.17T)	9180	2550	810

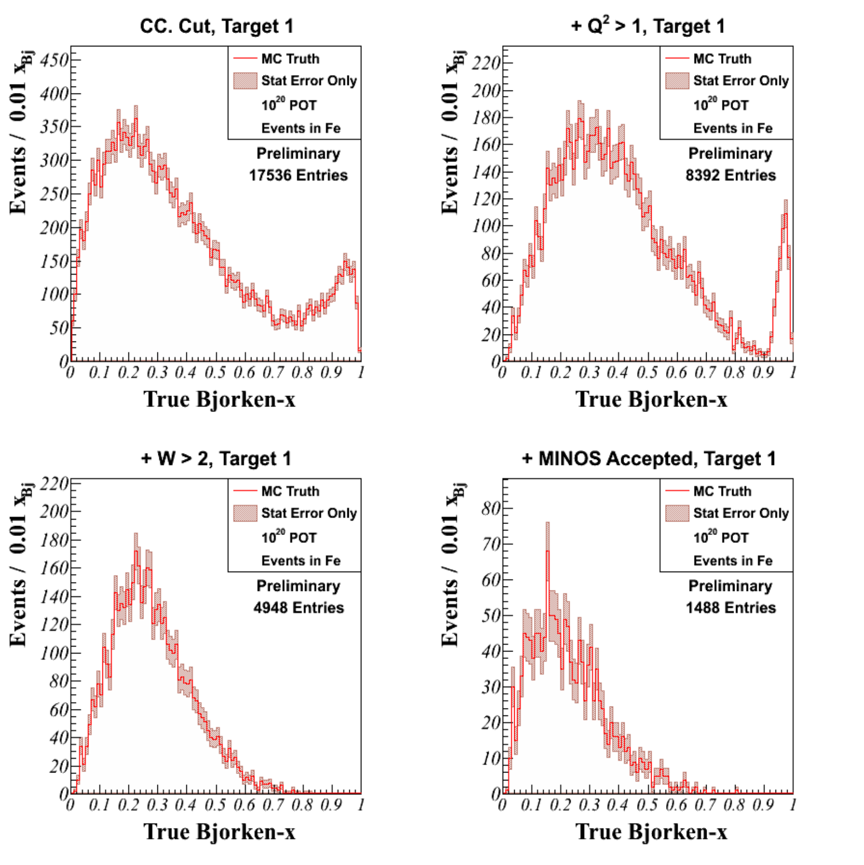
Key:
Gray = Pb
Red = Fe
Black = C



DIS Events in high A material: Target 1

*1x10^{20} POT, **1/4 of our approved LE data run***

Target	CC Events	CC DIS	MINOS accepted
Target 1 (0.58T)	32.7K	9110	2580
Fe (0.32T)	17.6K	4950	1490
Pb (0.26T)	15.1K	4160	1090



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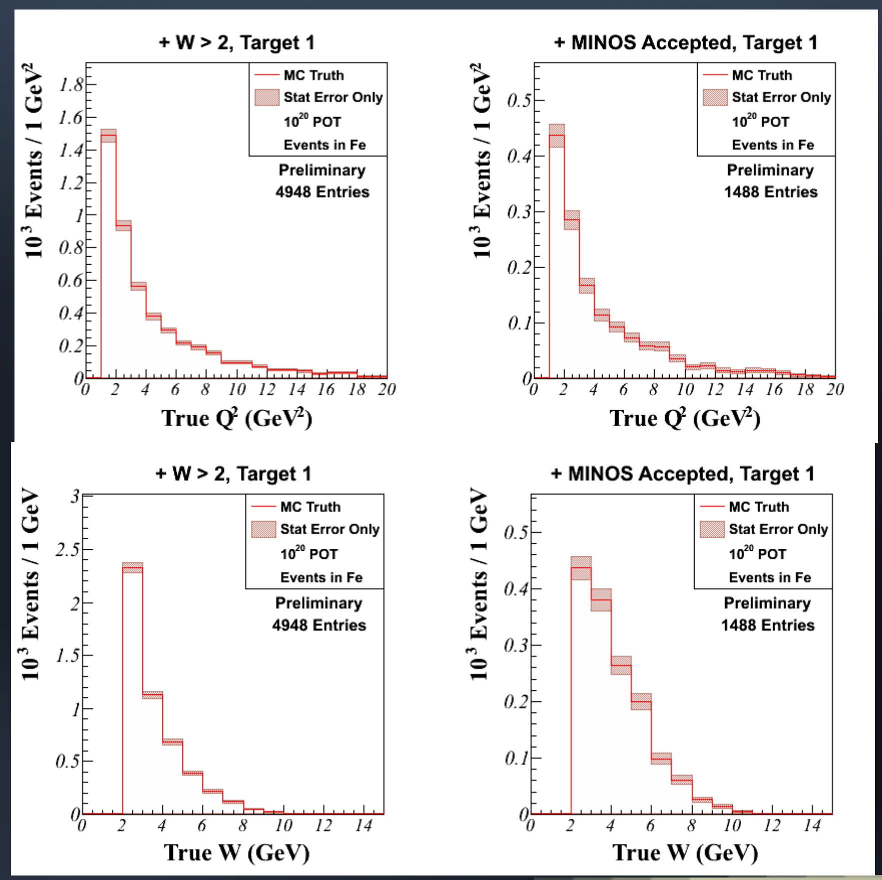
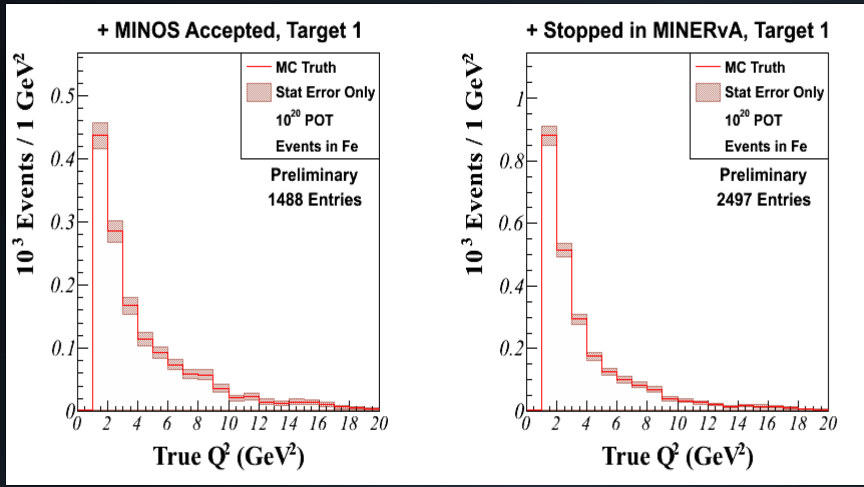


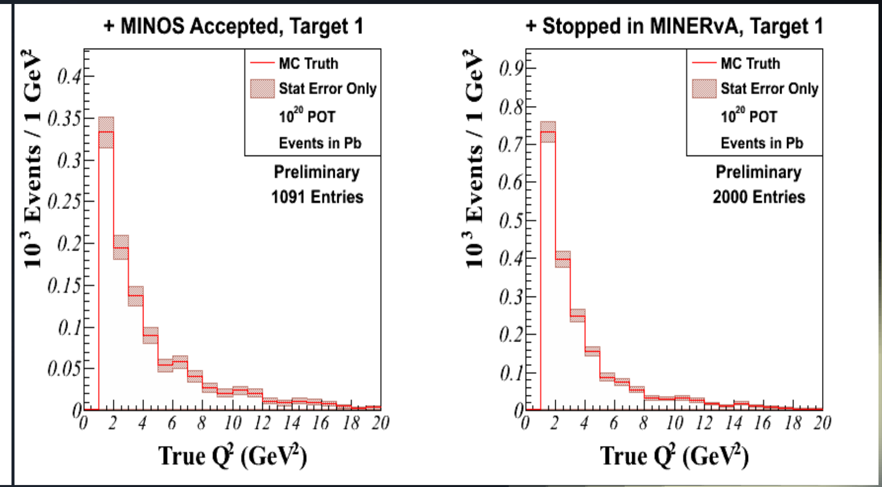
Increasing our Data Sample

- Additional Targets: over 80K events on Fe and Pb in full LE beam run!
- MINERvA loses many events by requiring the final state muon be tracked into MINOS.
- Acceptance is worse in upstream targets.
- We are actively working on improving our acceptance by analyzing muons which stop in MINERvA.

Target	CC DIS	MINOS Accepted	Fraction Accepted
Target 1 (0.58 T)	9110	2580	0.28
Target 2 (0.58 T)	9280	2720	0.29
Target 5 (0.30 T)	4660	1620	0.35
Tracker (5.0 T)	75.1K	30.1K	0.40

*1×10^{20} POT, **1/4 of our LE approved data run***





Event Rates Greatly Improve!

1x10^{20} POT, ***1/4 of our approved data run***

Recover almost 50% of lost events!

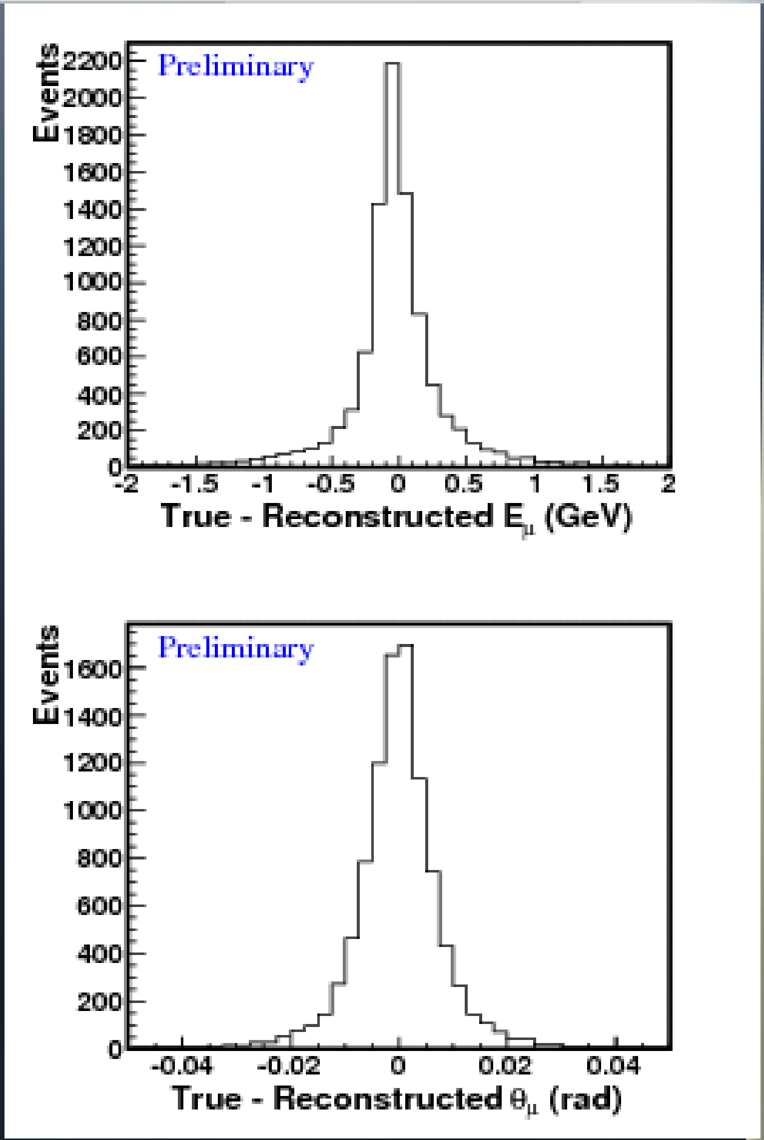
Material	CC Events	CC DIS	Stopped in MINERvA or MINOS	MINOS Accepted
Tracker (CH_2) (5.0T)	296K	75.1K	45.8K	30.1K
Fe (0.98T)	52.9K	14.8K	7680	4550
Pb (1.01T)	57.4K	16.1K	8370	4921
Graphite (0.17T)	9180	2550	1350	810

Reconstruction of DIS: Leptons

MINERvA currently measures muon energy in MINOS.

Use this information + tracking information in MINERvA to compute initial energy and production angle.

Residual of True – reconstructed muon energy and production angle for our anti-numu CCQE sample.



See K. McFarland, NUINT '11.

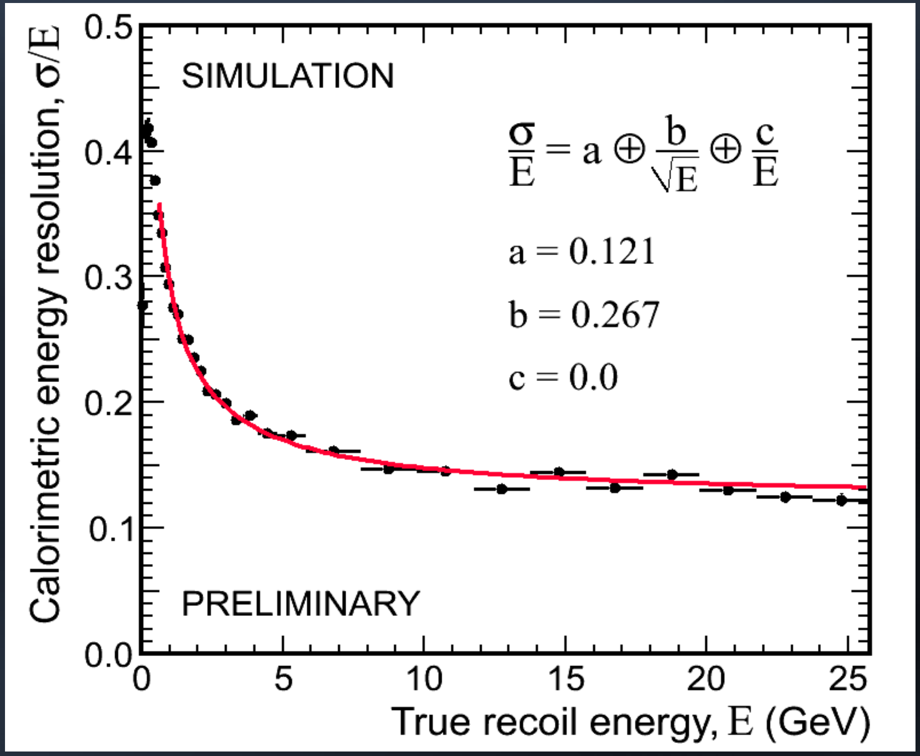
Reconstruction of DIS: Hadrons

Hadron reconstruction much less straightforward than lepton.

Cannot do simple dE/dx: need to measure shower energies and do calorimetry.

MINERvA's first attempt at calorimetry, done using the simulation of our detector.

Initial estimates of our energy resolution. MINERvA expects significant improvement as we develop our reconstruction



Hadronic Reconstruction:

- From resolution on E_{had}, calculate the contribution of dE_{had} to the uncertainty in W^2, x_{Bj} and Q^2.

- Fractional uncertainties due to dE_{had}:
  - W^2: approx. 10 to 20 %
  - Q^2: approx. 10%
  - X_{Bj} : approx. 5 to 9 %

- ONLY taking error on hadronic energy into account. NO error on lepton energy or angle taken into account.

MINERvA's Deliverables to DIS

- Analysis of transition to full DIS region.
  - Fine-grained detector give us excellent sensitivity to these topologies.
  - First systematic analysis of DIS events on He, C, Fe, Pb. Targets in the same beam!
- Much more data on the horizon!
  - Have not looked at ME DIS capabilities. Sure to be much greater than LE.
  - Have not looked at MINERvA's sizable anti-neutrino data sample.

Conclusions:

- MINERvA is operating, running and recording DIS events as we speak.
- Our multiple nuclear targets in an identical neutrino beam and high-resolution detector will add significantly to our knowledge of neutrino deep inelastic scattering.
- We're actively working on all aspects of a DIS analysis: simulation, reconstruction, and calibration.
- *Stay tuned for results soon!*

The MINERvA Collaboration

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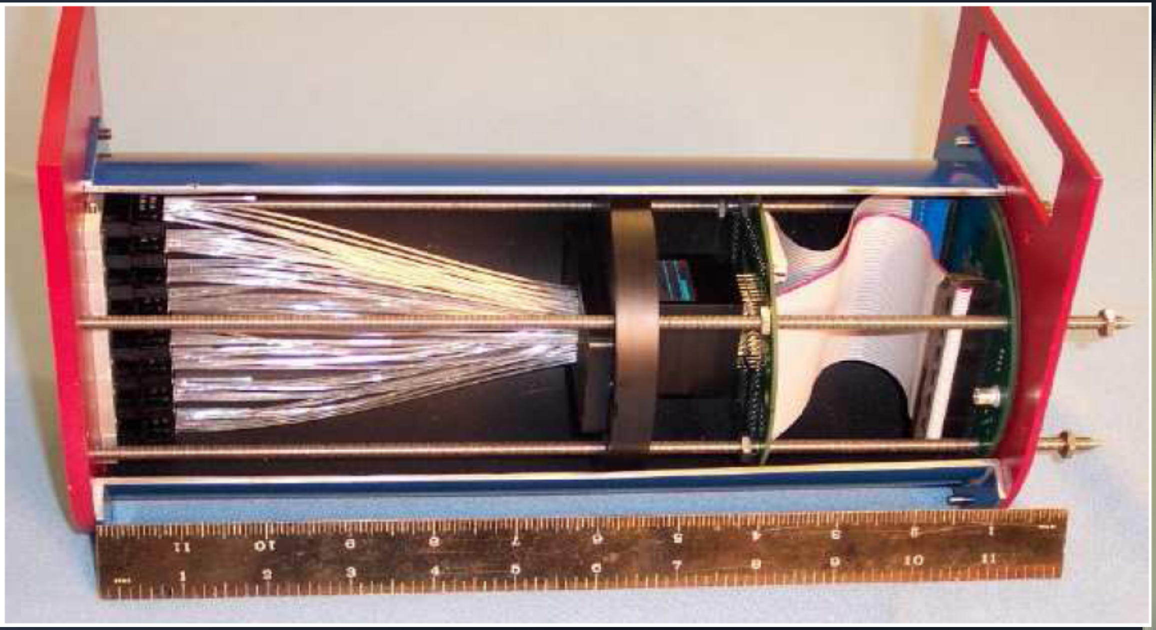
Thank you for listening!

Back Up Slides

MINERνA PMTs

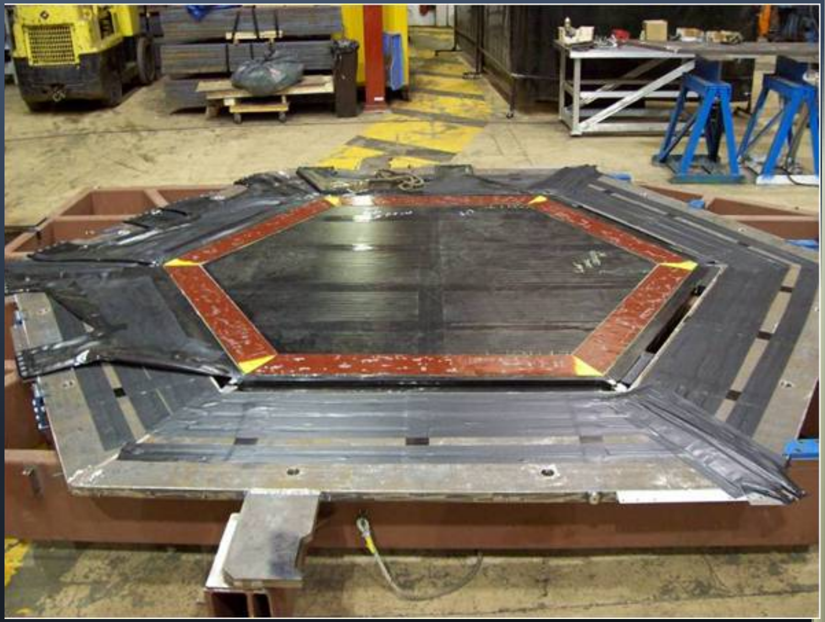
Light from the scintillator travels through the green WLS fiber, until it exits the plane.
Clear optic fibers carry the light from the plane to MINERυA PMT boxes (bottom right). Fibers inside the box carry the light to a Hamatsu M-64 PMT.
Fiber weave separates adjacent scintillator strips to non-neighboring PMT pixels to reduce optical cross talk.
Fibers terminate on a plastic “cookie” which mechanically mates with PMT base.



Cut away of a PMT box, showing the weave, cookie, and PMT. MINERυA has 507 PMT boxes installed.

Structure of Modules (cont'd)

- Target Module: One layer of target material (Fe, C or Pb) and one layer of scitntillator (5 modules).
- Tracker Module: Two layers of scintillator (84 modules) 3.71 interaction lengths.
- ECal module: Two sheets of lead, surrounding two layers of scintillator (10 modules) 8.3 rad lengths.
- HCal module: One layer of Fe + one layer of scintillator (20 modules) 3.7 interaction lengths.



MINERvA module under construction

In Situ Flux Measurement

- Variable beam configurations offer *in situ* flux method.
- Can check cross sections at single E_ν using several beam configurations.
- Measure event spectrum with QEL's.
- Normalize to high energy DIS
- Goal is 7% error flux shape, 10% norm.